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ABSTRACT

There has been a marked increase in recent years in research studies of the alternative "frameworks of thought" that learners bring to the interpretation of what they meet in school science. Provided are summaries of papers and discussions from a meeting which critically reviewed the methods being used in such research and their theoretical basis. The first section contains summaries of 14 papers which address various issues related to students' existing ideas about science. Sources for obtaining each entire paper and/or references are included. The second section discusses the range of methods used and the variation in intention guiding these inquiries, including the type of representation of results used and the learning theory or theories that the researcher believes. Presented in the third and fourth sections respectively are discussions on the origins of students' alternative conceptions and the value of these studies. (JN)

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INVESTIGATING CHILDREN'S EXISTING IDEAS ABOUT SCIENCE

A research seminar April 1982

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In recent years there has been a marked increase in studies of the alternative "frameworks of thought" that learners bring to the interpretation of what they meet in school science.

The principal purpose of this meeting was to review critically the methods being used in such research, and their theoretical basis.

Some of the questions we had in mind in setting it up were:

If learners have alternative and perhaps unexpected ideas, e.g. of what heat is, or how an electric current behaves in a circuit, how stable are these ideas over time?

....How do they arise? .. How do they change? ..Are some more resistant to change? ...Can changes followed & described?

How do feelings about the subject matter, and about oneself, affect the structure of ideas, and its capacity for change?

What are the consequences for research, and for teaching?

Rather than reproduce everything that was said and done, we have aimed to produce here a short report that captures the essence of the papers and discussions and which will at the same time provide ready access to the work and writings of the participants.

CRS & LHTW

SUMMARIES OF CONTRIBUTIONS

Outlines of papers presented or referred to p.4

THE RESEARCHERS AND THEIR WORK

I Variations of approach (Leo West) p.19

II An analysis of assumptions (Leo West) p.25

THE ORIGINS OF PUPILS' IDEAS

... and of changes in them (Clive Sutton) p.33

WHAT IS THE VALUE OF THESE STUDIES?

Can research influence practice? (Leo West) p.38

Ageha Claxton.
School Science: Falling on Stony Ground, or Choked by Thorns?

If the "seeds" of school science do not grow well, perhaps it is because the ground in which they are sown is already occupied by other species of idea. This paper elaborates a way of thinking about those ideas, and the problems they pose for the science teacher.

Ageha suggests that everyone has a multitude of small theories, substantially independent but sometimes overlapping, which might be brought to bear upon a novel situation. He describes the application of 4 such "minitheories" to a school problem of "What will happen to the water level in this jar if we drop a weight into it?". In this case, minitheories drawn from experience of boating on lakes, of getting into a bath, of putting sugar into drinks, and of jumping onto a bed, will each generate a different prediction about what could happen.

Ageha claims that a key feature of any minitheory is the range of SITUATIONS to which it is felt applicable. Since it will also yield PREDICTIONS, and guide its user in ACTIONS and in the DESCRIPTIONS and EXPLANATIONS he or she offers, it can be referred to more briefly as a S.P.A.D.E., a useful acronym for such a powerful mental tool. Learning consists in elaborating the power of a SPADE, and refining the specification of when it may be used.

A further section of the paper deals with various sources of minitheories, in personal enactive experience and in more verbal ideas encountered outside and inside school. There is a tabulated comparison of "gut science", "lay science" and "school science", which may remain insulated from one another, each elicited only in its own narrow range of situations.

The central problem of science teaching becomes one of dealing with conflicting minitheories. If the teacher's primary goal is to teach school science, then he may teach in such a way that conflict is avoided, but if the aim is to enhance real-world competence, then he must actively create conflict in his students, and support them in their efforts to achieve a resolution.

The paper is available from
the author at Chelsea College.
Readers may also like to consult:

Claxton, G. (Ed) (1980)
Cognitive Psychology: New Directions
London: Routledge and Kegan Paul

John Crookes
Personal Commitment during Changes in Explanation.
A Study of Mark, aged 14 years.

This account of Mark's explanations of phenomena involving heat was made possible because of a pattern of yearlong secondment which the Leicestershire Education Authority has recently given to some of its teachers. It has enabled them to observe for long periods in their own schools, or other schools nearby, paying particular attention to a few pupils.

The observer keeps a daily diary, and the pupils are also encouraged to keep a "thought book". Some conversations are tape-recorded. The narrative account presented on this occasion was built up using extracts from all those sources. It covers a period of about four weeks.

At first, Mark's explanations of how heat travels made great use of terms like "strong and weak rays" and "young and old rays", with reservations such as "there are other kinds of heat... I do not think have anything to do with rays." In his written thoughts he tries to explain how a rod gets hot, and what is happening in the milk pan he has watched at home. Eventually he comes to wonder about the effects of the expansion of solids, which he sees as a threat to the stability of objects:

"I would like to find out how things like coookers can get away with expanding and contracting every time they are heated."

Having subsequently taken apart a cooker, looked at steel beams in the roof, and checked the walls for cracks, he writes about how he decided to change his mind on some of his earlier ideas. The emphasis is on himself, and HIS ideas.

John draws particular attention to the acts of will, personal judgment and emotional commitment that appear in this episode, which appear to be a key part of the learning.

Copies of the study are available from the author at Countesthorpe College, Leicestershire.

For a discussion of the method of enquiry, readers may also like to consult the following:

Armstrong, M (1980)
Closely Observed Children
Chameleon Press, London.

Gaalen Erickson
Student Conceptions of three Vector Components

Gaalen has published a number of papers about children's understanding of heat and temperature, circulation, genetics and aspects of mechanics. His latest research is concerned with students' conceptions of vector characteristics that are basic to subsequent understanding of vectors in physics. It concentrated on implicit vector characteristics that are frequently pre-supposed in curriculum materials and in classrooms. These include the use of reference points for stationary bodies, frames of reference, the idea of change of location, the idea of simultaneous velocities, and several others.

The children (twenty grade 10 students) were interviewed about specific tasks that were within their realm of experience. For example, one task simulated a fishing trip on a lake (using a film loop and a cardboard model), and the children were asked to imagine that they were going on such a trip. Certain questions were included in a conversation about aspects of the trip, e.g., "How would you describe the location of this first fishing spot to your friend?"

The data were analysed by classifying the children, for each implicit vector characteristic (I.V.C.) into categories based on the inferred use of a rule. For the I.V.C. "Reference point for stationary bodies" the inferred rules were:

1. Each of the locations of fishing spot is described, using several bodies or places.

2. Each of the locations is described using only one reference body but a distinct one for each location.

3. Each of the locations is described using one unique reference body for all occasions.

This categorisation of children according to their use of inferred rules was repeated for each of the I.V.C.'s over a series of tasks similar to the fishing trip task. These context-specific rules were subsequently transformed to produce more general rule statements, which can be used as working hypotheses for future studies.

This particular study is the first in which the inferred rules approach has been used, although it is one of a range of studies. Overall these studies aim to identify patterns of pre-instructional knowledge that may aid or inhibit the learning of the concept in science classes. Knowledge of these pre-conceptions should be of value to seience teachers and to curriculum designers.

The full paper is available from the author at the University of British Columbia.

Readers might also like to consult:
Erickson, G.L. (1979), Children's conceptions of heat and temperature, Science Education, 63, 221-230.

Elizabeth Engel and Rosalind Driver
Investigating Children's Ideas about Pressure

The specific research reported was an investigation of children's knowledge of pressure, including several aspects of pressure (e.g. pressure and depth, atmospheric pressure). Students answered written questions and were interviewed using the same questions and some additional tasks based on concrete materials. Eighty-four pupils were involved (thirty aged 12, thirty aged 14 and twenty-four aged 16). The 12- and 14-year olds were re-interviewed on the same questions two years later.

The research questions investigated were:

1. Do common patterns of belief exist? ..and if so, what are they? ..and with what frequencies do they exist in a population of 12-16 year olds?

2. Do individuals employ the same frameworks across similar questions in different but parallel contexts?

3. How stable are the frameworks over time?

The short answers to these questions were:

1. That it <u>is</u> possible to identify common patterns of belief and to determine their frequencies in different populations.

2. That some pupils do employ the same pattern across parallel tasks. Others, however, do not.

3. That over a three-year period, some pupils do retain the same framework, but it is more usual for them to shift. The frequency of alternative frameworks at a particular age appears stable, however. At a more general level, Liz suggested that some pupils tend to "layer" school knowledge separately from their real-world knowledge without relating the two.

In analysing the data, pupils' words were transformed into categories of response to a particular question. These categories were generally of two types: some were ordinal (correct, partly correct, on the way to being correct); others were 'incorrect' and of distinct types. Categories for parallel questions were then compared, and common responses across contexts were used as evidence of the existence of pupil frameworks relating to a particular scientific idea. Frequencies of the incidence of these frameworks could then be determined.

Copies of this paper are available from the authors at the University of Leeds. Readers may also like to consult:

Engel, M.E.T. (1982), The development of understanding of selected aspects of pressure, heat and evolution in pupils aged 12 and 16 years. Unpublished Ph.D. thesis, University of Leeds.

John Head
There's more to changing your mind, than changing your mind.

In a personal reaction to the presentations made at the seminar, John highlighted these questions:

1. DO children hold "alternative constructs"?
In the context of a science lesson the term still may imply a "right" construct that the teacher has. How would a teacher of English literature handle "alternative" interpretations of a novel? Observation of those classes migh be relevant to this work.

2. Can they be ascertained and described?
It appears so, and also that they may fall into some sort of pattern. Sometimes the child's ideas resemble the established theories of earlier times, and in some cases there might be a developmental sequence of such ideas. Sometimes a person's minitheories might be partially determined by the social group to which he or she belongs.

3. Do the existing constructs block learning - resisting change?
Yes, said John, in several ways:
a) In a logical way. The teacher's science may seem crazy - an offence to the child's common sense.
b) Socially. The teacher's ideas do not fit in with the peer group folk wisdom (Even the descriptive language may be different).
c) In personal development. These ideas the teacher has don't fit me as a person. I am who I am partly because I think as I think.

4. Are there any pedagogic implications?
Yes, said John, and it is not enough just to provoke some cognitive dissonance. All pupils will have ways of defending themselves in that situation, including the use of a dismissive statement like "I cannot understand physics", or compartmentalising their minds so as to diminish conflict. Another approach might be to get them involved in a metacognitive awareness of their own belief systems. Role play might provide a safe way to that awareness.

In summary, John asked "What is the pay-off for learning, for taking on board any new views?" Certainly there is no motivation to change if new ideas are not part of your peer group's views, nor make sense to you personally.

Readers may also like to consult the following:

Head, J.O. (1980) "A model to link personality characteristics to a preference for science" European Journal of Science Education, 2, 295-300.

Head J.O. and Sutton C.R. (1981) "Structures of understanding and the ontogenesis of commitment" Paper presented at the Cognitive Research Seminar, AERA, Los Angleles, 1981.

Leon Pines
The relevance of studies of cognition for science education

Leon too was asked to react to the earlier presentations from the perspective of his own work. There are two sides to his work - understanding how concepts develop in children and how concepts develop in the disciplines. The former includes his work on clinical interviews about conceptual knowledge and analysing clinical interview data. The latter includes his analysis of the concept of a 'concept' and the meaning of 'meaning'.

Leon raised two challenges to the participants. Firstly he asked them to examine the value of this area of research. Within the prevailing conditions of schooling - at least in the USA - he raised some doubts about whether the research has any implications for science education. His analysis of the aims of science education and of schools suggests a lack of congruence with the type of learning being considered in this research. Even if there are no applications, theoretical advances may be important in their own right - at the very least they provide us with considerable intellectual stimulation. Is this sufficient justification?

Secondly, Leon warned of the danger inherent in adopting elegant theoretical models which have potential to generate whole families of research projects even if incorrect. He pointed, as an example, to his own work on the conic model of a concept. This model is elegant, has appeal, and would provide literally hundreds of research questions. Yet it fails to represent human concept development. The problem seems to be that more precise theoretical models become both more remote from classroom practice and more difficult as research programmes. Thus they are less likely to gain a foothold.

Readers may like to consult:

Pines, A.L., Novak, J.D., Posner, J.J. and Van Kirk, J. (1978), The Clinical Interview: a method for evaluating cognitive structure, Research Report No 6, Curriculum Series, Department of Education, Cornell University.

Pines, A.L. (1980), On Concepts and their Acquisition, ERIC Document ER 196 677.

Maureen Pope and John Gilbert
The Personal Construction of Knowledge Group

The research undertaken by this group at the Institute of Educational Technology at Surrey University is conducted within a framework of George Kelly's model, and some of its core assumptions were described, for example:
- that people construct their own knowledge;
- that concepts are not learnt through the passive accretion of components but through the active imposition of meaning by the learner;
- that learners are not isolates. Personal constructions are influenced by the interactions between people in their discussions about meaning.

Some implications of this approach, for both research and teaching are:
- the importance of NEGOTIATION between teachers and children about the discipline, and the curriculum;
- the presentation of scientific knowledge as CONJECTURAL and PROVISIONAL.

Two of the methods used by the group for investigating children's ideas were discussed:

1. The INTERVIEW ABOUT INSTANCES
2. The REPERTORY GRID method.

Maureen demonstrated the latter, using an interactive computer program.

The Interview-about-Instances has been used for some time, and has evolved to include conversations between learners without a researcher or teacher present. A videotape of such a discussion was shown. That may be useful as a teaching device as well as a method for investigating the students' ideas. It encourages them to articulate their personal meanings and to confront alternatives. In subsequent sessions the teacher could then discuss the range of alternatives highlighted by the students, so that negotiation of knowledge is facilitated.

Readers might like to consult:

Kelly, G.A. (1955) The Psychology of Personal Constructs, Vol 1 & 2 New York: Norton.
Osborne, R.J. & Gilbert, J.K. (1980) A technique for exploring students' views of the world Physics Education, 15 (6), 376-9.
Pope, M.L. & Keen, T.R. (1981) Personal Construct Psychology and Education. London: Academic Press.

Keith Ross
Concepts in Science, and the Effects of Home Language

Keith has studied secondary school pupils in England, and also in the Tiv-speaking area of Nigeria. In the latter case, some have English as their home language and some do not, and comparisons can be made of the corresponding subgroups. The method of study involves free definitions by the pupils, of groups of related words, and collection also of their free associations to the same words.

Concept profiles emerge for common words such as BURN, LIGHT, and ELECTRICITY. Cultural background is markedly influential upon the way in which the pupils use these terms, but school usages are not spontaneously linked by any of the language groups to the "meaning" they ascribe to the same words out of school. Potentially such concept profiles could be useful in alerting teachers to the usable knowledge that pupils have in the area of particular concepts of "public" science.

Readers may like to consult:

Ross, K.A. & Sutton, C.R. (1982) Concept Profiles and Cultural Context European Journal of Science Education pending.

Joan Solomon
Pupils' Background Ideas about Energy

This account involves enquiries into the folk-meanings of "energy" in the adult community, and a study of explanations and uses of the word by 11, 12 & 13 year olds who have not received any formal instruction about the topic.

As an example, 11 year-olds asked to explain what the word means include in their answers many references to strength, power, force and activity. However, using the word in sentences there is much more reference to human contexts - with people feeling energetic, running out of energy, building up their energy etc.

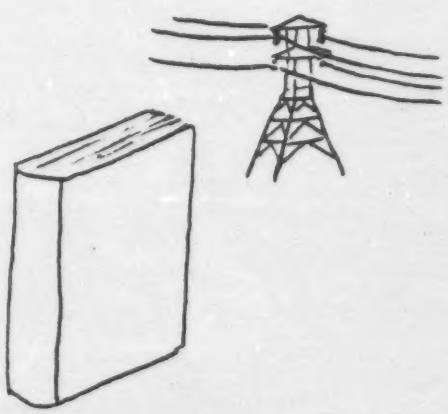
Part of the paper developes the idea that there are two contrasting themes - to do with HUMAN VITALITY and HUMAN ACTIVITY. Pupils' responses were categorised into these two types. The latter, it is suggested, may be a necessary, but not a sufficient, criterion fo moving towards a more universal notion of energy, and awareness of its public scientific denotation.
The connections between these ideas and certain aspects of the historical development of the concept are discussed, as are some interesting differences in the connections of the English words ENERGY and FORCE, as compared with the German words ENERGIE and KRAFT.

Asking pupils to use the word in context appears to be potentially a powerful way of gaining insight into the folk theories to which a person gives allegiance. Joan emphasises the social dimension to accepted meanings, reminds us that teaching is a social process, and seeks to establish what research methods are most appropriate in that context.

Copies of the full paper are available from the author at Chelsea College.

Readers may also like to consult:

Solomon, J. (1980)
Teaching Children in the Laboratory.
London: Croom Helm



David Shipstone
Pupils' Understandings about Electric Circuits.

David's research involves pupils in the first four years and in the sixth year of secondary schools. Pencil and paper tasks are used, with a set of ten questions about the distributions of current and voltage in a circuit, and the effects of resistance on these.

The aims have been:
"...to investigate the erroneous rules and models that pupils use in reasoning about electrical circuit behaviour,
...to explore the possibility of arranging the misconceptions heirarchically, establishing which are consequential upon which, and
...to see if children's reasoning about electrical circuits can be represented by rule-models. "

So far, the principal outcome has been a description of what David calls the "sequence model". Children who subscribe to this appear to think that the current flowing round a circuit is affected by each circuit element in turn. Thus if a rheostat which is situated after a lamp is altered, they predict that the brightness of the lamp will remain unchanged, since the current has already left the lamp and passed on by the time it reaches the rheostat.

Nearly 70% of third and fourth year pupils (aged 13 & 14) appear to use this view, and 40% of the sixth year pupils still do. That current decreases as it flows round the circuit is a logical consequence of the sequence model, and amongst older pupils the two views do seem to be closely associated. Many of the younger pupils however are believed to have arrived at non-conservation in a more intuitive way.

Amongst able pupils, the incidence of the sequence model peaks at around 90% in the third year. Its incidence amongst less able pupils was lower in the first three years, and still growing at the end of the fourth year. This suggests that, given time and sufficient teaching, virtually all pupils will imagine current to behave according to the sequence model at some point in their learning.

Further details are available from the author at Nottingham University.

Clive Sutton
The language of science.

This paper is about aspects of language use in the scientific community that bear upon the evolution of understandings.

Some features which are desirable for the practice of science are also a handicap in the context of teaching and learning, because they conflict with the encouragement and enrichment of "private understandings" in the mind of each learner.

The insistence on definiton, and the suppression of peripheral aspects of meanings, encourages the belief that the agreed public denotation of a scientific term constitutes the only part of its meaning that need concern teacher and learner. It seems unnecessary to explore just what each person's provisional understanding is, and the question of "negotiation" or of sharing meanings does not appear to be part of the task.

Historical examples of the change in the meanings of words alert us to the realisation that meanings are never fixed. These examples can be used to illustrate the conjectural character of scientific knowledge, and to encourage pupils to look for changes in the meanings that they themselves ascribe to the terms they encounter. ..... Changes in conceptual structures seem to be closely linked with such changes in meaning.

The paper is available from the author at the University of Leicester, or in the International Encyclopedia of Education (editor: T. Husen).1982.

Readers may also like to consult:

Sutton, C.R. (Ed) (1981)
Communicating in the Classroom,
Introduction: "Making sense of new ideas",
London: Hodder and Stoughton.

Sutton C.R. (1981)
"Metaphorical Imagery - A means of coping with unfamiliar information"
Durham & Newcastle Research Review ix 46, 216-222.

> we cannot improve the language of any ſcience, without at the ſame time improving the ſcience itſelf; neither can we, on the other hand, improve a ſcience, without improving the language or nomenclature which belongs to it.
>
> Lavoisier 1789

Leo West
Describing the cognitive structures of undergraduate chemistry students

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Leo provided an overview of research aimed at describing the cognitive structure of undergraduate chemistry students during several teaching sequences. He emphasised that this research was more concerned with the process of description than the particular description itself, and indicated applications to teaching - providing a vehicle for feedback about integration and differentiation of conceptual knowledge and a study method for students (meta-cognition).

The descriptions of cognitive structure include networks of propositions that emphasise the structure and nature of conceptual relationships, networks that include intellectual skills and examples, and in-depth descriptions of knowledge related to specific propositions. Methods have been developed to transform these individual representations into scores on a set of dimensions. These allow summaries for groups. The dimensions include integration of propositional knowledge, differentiation of propositional knowledge, differentiation of skills/examples of knowledge, depth of propositional knowledge, and articulation of propositional relationships. At this stage he prefers to call these indices rather than scores, because of the need for validity checks.

In one study of the application of the techniques to science classes, eleven chemistry students were shown how to describe their own cognitive structures. It was found that they had no problems in learning to use the techniques; that the results were valuable feedback to the teacher, and the students thought that it helped their learning.

For further details see:

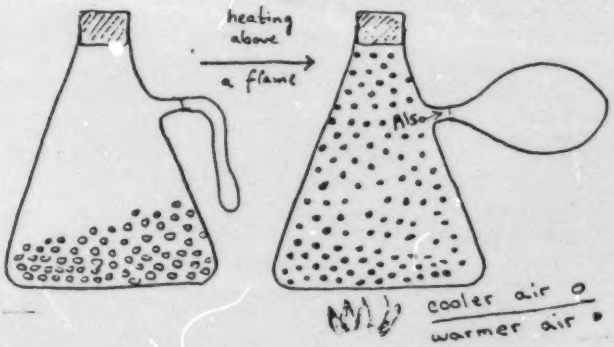
West, L.T.H., Fensham, P.J. and Garrard, J. (1982) Describing cognitive structures of undergraduate chemistry students, unpublished report, Monash University (Australia).

Joseph Nussbaum and Shimshon Novick
A study of conceptual change in the classroom

The authors were not present at the seminar, but sent a paper, which we discussed. This summary concentrates on those parts of it which are about MONITORING and INFLUENCING concept change.

The study aimed both to monitor change and to assess a teaching strategy that was designed to promote change. The topic was the kinetic theory of gases - a ten lesson sequence over four weeks. The teaching strategy involved an "exposing event" in which the students, in attempting to articulate their explanations (through drawings) "exposed" their alternative frameworks. These were written on the chalk board, discussed and debated by the class, and after some readjustments by individuals were allowed to stand relatively value-free. It was hoped to produce a general awareness of other students' alternative frameworks (and one's own). A "discrepant event" was then introduced to create conceptual conflict, and the students were again asked to articulate their explanations and to share them with the class. Over the four weeks this strategy aimed to encourage and guide cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific framework.

Yossi and Shimshon devised a taxonomy of student alternative frameworks (SAF's) for the topic, and then classified each student at various times during the ten week period into one of the six categories of the taxonomy.



Before: The air wasn't heated so it didn't really make the balloon rise.

After: The air was heated, so it made the balloon rise

A small part of one pupil's drawings, as shown in the paper, and part of the authors' commentary.

worksheet 7

Indicates use of a particle picture, but assigns to particles bulk properties of air

The full paper is available from the authors at the Hebrew University, Jerusalem.

Rosalind Driver and Gaalen Erickson
The Study of Conceptual Frameworks: a meander in the field.

As well as describing examples of their own research, Ros and Gaalen presented a discussion paper surveying the field, although they preferred to describe it as a "meander" in this field rather than a formal review. Their analysis considered:

1. PURPOSES of research (compare INTENTIONS, p19)
2. THEORETICAL ISSUES
3. METHODOLOGICAL QUESTIONS
4. PEDAGOGICAL ISSUES

They distinguished strongly between theory-driven and problem-driven research, the former having a strong focus on a particular theoretical model, the latter being more eclectic and concentrating on the problems of promoting learning. They described their own work as mainly problem-driven (the reflective practitioner-in-action trying to find solutions to a problem), while accepting that in pursuing a solution to an actual problem various theories may be illuminating. Kelly's Personal Construct theory, Ausubel's Theory of Subsumption, Information Processing models and Piaget's assimilation-accommodation model are all used by various workers, and this kind of theory also influences the views that problem-orientated researchers have about the origins of pupils' ideas. (They mentioned kinaesthetic sense experience, and language, as two possible sources of these ideas.)

They suggested that there are three widely shared assumptions:

i) some form of cognitive structure is presupposed. (Perhaps a structure of content-independent processing skills, but for most of the newer investigators a structure of content-dependent elements such as particular concepts or propositions.)

ii) a constructivist epistemology is also assumed,

iii) it is taken on trust that understanding children's ideas is important for the classroom.

The biggest variation in emphasis is between studies that examine changes attributed to instruction and those concerned with students' spontaneous belief systems derived from experiences prior to instruction.

A second variation concerns assumptions about the stability of children's ideas. Some focus on states of thought which are presumed to be relatively stable. Others assume that ideas are largely fluid, in which case there is little point in describing particular states, which may be transitory.

Turning to methodology, they outlined differences in how tasks are framed, the data collection methods, the representation of results and the nature of knowledge claims made. A range of techniques and examples of their use was presented, and several methods of representation were mapped along a dimension from formal to informal. In discussing the nature of knowledge claims, the types of inferential leaps made by the investigators were examined, and how far they claim the results to be generalisable.

In a final section on pedagogical issues, Ros and Gaalen returned to the question of whether students' prior knowledge matters, and the resulting implications for instructional design. A review of some of the small amount of research in this area was made, and they urged that more attention be given by researchers to this area, to demonstrate whether, and in what areas, prior knowledge impedes or interferes with intended instructional outcomes. (It might be that "common sense" frameworks simply co-exist with those constructed around school learning.)

The paper was concluded with a note on terminology which provided descriptions of some of the common terms being used (such as "misconception", "preconception", and "alternative framework").

If you get a battery and a wire and a little bulb like we did and put them to gether properly the bulb will light up but you must have made a circle But if you put the wire on the same little piece of metal the bulb will not light up because one piece of metal is the in door and the other is the out door But you need a bulb so there is something to light up. If you have something that is not metal it will not work.

THE RESEARCHERS AND THEIR WORK

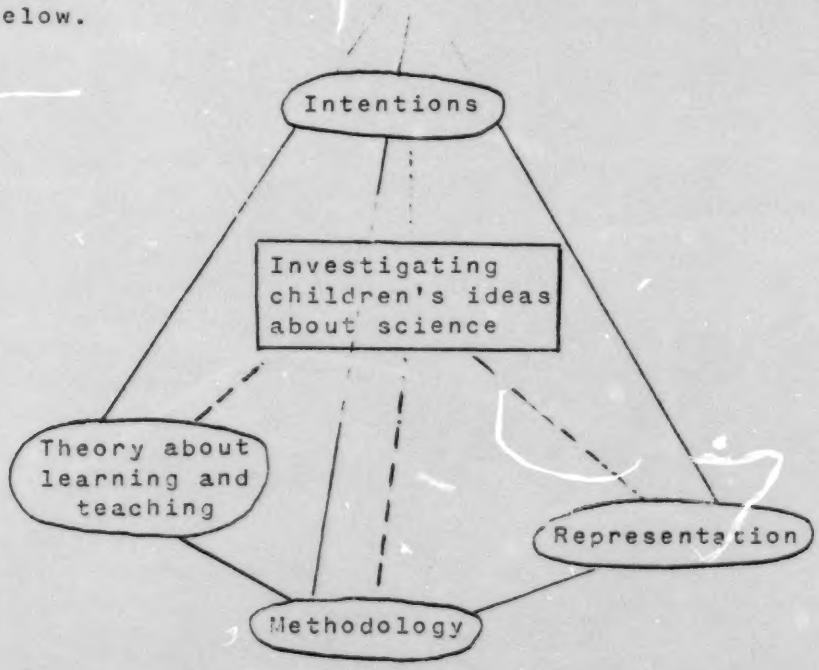
by Leo West

I. Variations of approach

During the seminar most participants described their approach, either in general terms or by discussing a particular example, as indicated in the summaries given in the previous section. On the second day I tried to draw up some comparisons and contrasts under a set of headings, and these were displayed on the wall so that people had a chance to make changes. The following is an outline of what survived, in which we can see both the range of methods used and the quite considerable variation in intention that guides the enquiries. The headings I have used are:

- INTENTIONS ("purposes" in the analysis of Ros Driver and Gaalen Erickson),
- METHODS,
- The TYPE OF REPRESENTATION of the results that is used, and
- the THEORY or THEORIES ABOUT LEARNING that the researcher believes.

These factors are not independent; for example the theory guiding the study affects the system of representation and this will influence the method of collecting the information, and so on. Neither is the relationship static. Any attempt to investigate children's ideas will lead to changes in one or more of the other factors. Thus it is sensible to think of these factors as both influencing and being influenced by each other. I have tried to represent these notions in the figure below.



INTENTIONS

(Note: Participants' research may be classified in several places. Also I have used the word intentions in a broad sense, to include applications and uses, after-the-event)

1. To identify students' alternate frameworks (A.F.'s), which are then communicated to teachers, curriculum designers, etc.

Liz Engel and Ros Driver. The concepts investigated include HEAT, PRESSURE, EVOLUTION. They use the term PUPIL FRAMEWORKS, and are also interested in changes in these A.F.'s with age, and in the consistency of their application.

Gaalen Erickson. The concepts investigated include HEAT and TEMPERATURE, VECTORS and GENETICS. He uses CONCEPTUAL INVENTORIES and INFERRED RULES as ways of describing the A.F.'s.

Maureen Pope and John Gilbert. The concepts investigated have been FORCE, WORK, ENERGY, LIGHT, HEAT.

David Shipstone has studied students' ideas about ELECTRICAL CIRCUITS, postulating the existence of "erroneous models".

Joan Solomon has investigated the concept ENERGY.

Leon Pines. His research concerned the concepts ENERGY, LIFE and FOOD. He is also interested in changes with age and consistency in individuals.

2. To understand how students try to make sense of their world and/or the scientists' world.

Liz Engel and Ros Driver - through changes over time in students' A.F.'s and through the consistency of responses to different contexts.

Maureen Pope and John Gilbert - through observing learners in the process of constructing knowledge.

3. To develop improved teaching methods.

Gaalen Erickson - aims to develop teaching strategies to help teachers deal with the "conceptual problems in the classroom".

Joseph Nussbaum and Shimshon Novick - have investigated the value of students articulating their A.F.'s in class and the use of activities that introduce conceptual conflict (i.e. discrepant events) to help students evaluate their own and other students' A.F.'s.

Maureen Pope and John Gilbert - especially through the "negotiation" of knowledge between pupil and teacher and pupil and pupil.

David Shipstone - investigated teaching procedures to removederroneous models.

Leo West. In my own work with Peter Fensham and Jan Garrard, we tested the use of research techniques by students on themselves as a means of providing feedback to teachers and as a way of rewarding attempts to integrate and differentiate knowledge.

4. To provide alternative study methods for learners.

Leon Pines - getting students to "unpack" (analyse) the knowledge claims in some component of teaching or of part of a text book.

Leo West - My colleagues and I have tried instructing students in the methods of describing their own cognitive structures. We were influenced in this direction by Joe Novak.

5. To test or refine theory, or gather evidence for particular positions.

John Crookes - spoke of seeking evidence to support the teaching approaches being used in his school.

Leon Pines - He investigated the interaction between students' cognitive structure and a teaching sequence, observing both convergence and divergence (Ausubel).

Maureen Pope and John Gilbert, using Kelly's personal construct theory.

Clive Sutton - seeking to clarify the relationship between pupils' use of language and the elaboration of their cognitive structure.

Methods used vary both in the technique of data collection and in the context in which it is collected. The latter may be task specific, content specific or concept specific. "Task specific" refers to situations when the student is requested to complete a particular task (e.g. to sort cards, to solve a problem, to explain an observation. "Content specific" situations are ones where there is a defined content area - usually defined by a teaching sequence. "Concept specific" studies focus on a particular concept word, such as energy.

Techniques vary from unstructured interviews, through paper and pencil tests, to students' own descriptions. Some researchers who did not attend the seminar are included so that an example of their technique is included. These are marked with an asterisk, and references are given on page 32.

TECHNIQUE	CONTEXT OF USE		
	Task Specific	Content Specific	Concept Specific
Unstructured interview	Crookes		*White (Eucalypts, Electricity)
Semistructured interview	Gilbert: Interview about instances.		Erickson (Heat, Temperature etc) Engels & Driver (Pressure, etc) Pines (Life, Energy , etc)
Pencil and paper tests/ tasks	Shipstone	West et al (Skills test, Matching tasks)	
Card sorting		*Champagne (1979)	
Word associations			*Schaefer Ross
Free definitions		West et al (propositions)	Solomon (energy) Ross *Schaefer
Students' descriptions of own knowledge	Crookes Nussbaum and Novick		Solomon (energy)
Diaries of conversations	Crookes	Crookes	

Representing students' ideas is one of the major problems. Information gathered from individuals often runs to several pages in length, and needs to be reduced in some form for communication to others. Further, there is the problem of combining data from several individuals in order to produce group summaries that do not lose too much of the richness of the individual descriptions. Some researchers only present data for individuals; some only for groups; other present both.

Data for individuals

I(i) Concept maps or networks, with nodes and links.

Leo West: An example is my use of propositional networks based on relationships, with skills, examples and sometimes images added on.

I(ii) Categorisation schemes, in which categories of belief are described and an individual is classified as adhering to one of these.

Liz Engel and Ros Driver, Gaalen Erickson, Maureen Pope and John Gilbert and also David Shipstone all use variations of this type.

I(iii) Extended discourse, in which the original data is reduced or transformed but still presented as extended prose.

Leon Pines used lists of transformed propositions, and I have been influenced by him and used the same approach in representing depth of knowledge.

Data for groups

G(i) Scores (and means) on particular scales or dimensions.

Leo West: We have used scores on a set of "indices" as summarising measures of cognitive structure.

G(ii) Categorisations - numbers or proportions of students in particular categories of AF's are presented. Sometimes 2-dimensional

Liz Engel and Ros Driver, Gaalen Erickson, Maureen Pope and John Gilbert and Joan Solomon use these representations in various forms.

G(iii) Burr diagrams - a core of denotative meaning with "hooks" to various connotative associations, perhaps subdivided

Gerhard Schaefer most extensively, also Keith Ross and Clive Sutton.

I have made no attempt to locate participants with particular learning theorists; indeed, as I indicate in the next part of the report, I am uncertain of the value in doing so. What may be valuable is to note the metaphors used by participants as they presented their own and discussed others' research. They may give the reader some more insights into the various participants' theoretical perceptions!

- Is prior knowledge a BARRIER or a BUILDING "BLOCK"? (used by Gaalen Erickson, John Head and others)
- Learning is NEGOTIATION between learner and the material to be learnt. (used by Liz Engel, Maureen Pope, John Gilbert)
- Learning is the CONSTRUCTION of knowledge (used by Maureen Pope).
- Concepts are the LOCI of meaning (used by Leon Pines)
- Changes in the meanings of concept words are shifts in the CENTRE OF GRAVITY of the set of words that define the concept (used by Clive Sutton)
- The basis of representation was a PROPOSITIONAL SKELETON (my contribution).

A PAUSE TO REFLECT ABOUT WHERE WE ARE

What I have done so far is to describe the work of the participants in a simple summarising framework, which allows comparison of the approach of any individual with that of others. In this connection I refer readers also to the review paper by Driver and Erickson (summarised in pages 17-18).

My own descriptive summary had another function. It provided for me a stepping stone to another analysis which attempted to understand (as opposed to just describing) what the participants were doing. This analysis, which follows immediately, is a personal one. It is, to use the language applied to school learning during the seminar, my "reconstruction" of the knowledge assimilated during the meeting. I include it in that spirit.

by Leo West

II. An analysis of assumptions

This analysis is an attempt to get below the surface of the researchers' descriptions - to articulate what I think explains the nature of the research they undertake and the opinions they expressed about the various issues raised during the seminar. I am on dangerous ground here. It is difficult to separate other people's perspectives from one's own, and it could be presumptuous to classify them (though as researchers they, and I, classify our subjects all the time!) Certainly it is extremely difficult to do so in a value-neutral way. Nonetheless, here is an attempt, which I hope will at least be provocative of thought. I apologise to all for any injustice done to them.

I am indebted to Leon Pines for his help as these ideas were worked out - both during the seminar in the early hours of the morning and in the days immediately following. He may not necessarily agree with my ideas, but he certainly influenced them.

Positions shared by the researchers

Some adopt an explicit theoretical framework. For example, Gilbert and Pope spoke about their work within a Kellian model. In other cases the theory is not so strongly stated, but an influence is acknowledged. Various of these public theories might at first glance seem worth using. Some that come to mind are those of Ausubel, Gagné and White, Kelly, Lindsay, Rumelhart and Norman, and Wittrock. The problem is that they seem not to discriminate very well between the researchers. There are many similarities within this group of researchers, consistent with all or most of the theorists mentioned. Differences of approach are not readily explained by adherence to a particular theory. I think, however, that some of these differences can be explained by a perspective developed below. It may perhaps overemphasise their differences, and de-emphasise the very considerable commonalities. Therefore it is important for me to note these very considerable agreements first, especially as many of them are out of step with much of the beliefs about learning that exist in the education community at large.

All are interested in children's thinking - or what is going on inside kids' heads. (This contrasts markedly with the behaviourists, who treat the learners as black boxes, concentrating exclusively on inputs and outputs.) All also share an

interest in content-related conceptual development, rather than in general intellectual development. Such commonalities are no accident. This was an invited seminar. We would be surprised if such general perspectives were not shared. As the seminar progressed there were a number of more specific similarities that emerged. The list below is probably not complete, nor are the items totally independent of each other. With those qualifications, some of the common beliefs of the participants are:

. Learning is more than repeating in near verbatim form what has been presented. It involves students in constructing their own meaning from the formal and informal inputs.

. Conceptual knowledge is idiosyncratic, as individuals construct their own meanings (or private understandings). However, there is, because of social interactions, considerable overlap in these private understandings of individuals.

. Concepts are not fixed entities that people have or have not - they are continuously changing as people develop and learn.

. Useful information about students' learning can be collected, in part at least, using interviews.

. The learner's existing knowledge is important in subsequent conceptual learning.

. Distinct, sometimes contradictory ideas can exist simultaneously in individuals.

Revolutionary versus Evolutionary emphasis?

There appear to be two distinct perspectives concerning conceptual development existing within the group that met at Leicester. Let me call them, for the moment, a revolutionary perspective and an evolutionary perspective, although I am aware of some weaknesses in that analogy. I am not sure, at this stage, whether I should consider them as mutually exclusive, as overlapping sets, or as ends of a bipolar dimension. For the moment I do not think that matters. Some difference does exist and seems important in discriminating between researchers at this seminar. I will consider them as separate, though I do not wish this to imply a mutual exclusion.

From a revolutionary perspective position, a child holds a particular theory (or theories) which help explain aspects of his/her world. Various names are given to these, viz., alternative frameworks, personal constructs, mini theories, gut theories, etc. When the child meets some new phenomenon which is not explained by his theory, that person may take various actions, but conceptual change means abandoning one framework and accepting another.

From an evolutionary perspective position the child also tries to make sense of his world, but by relating new observations to his existing knowledge, altering aspects of that knowledge (and probably the observations) to achieve consistency. From this perspective, concepts develop and expand through integration and differentiation.

I should emphasise that I am talking here of perspectives, not theories. A theory could accommodate both these forms of development - indeed several do. What I am emphasising is the particular ways in which researchers appear to be viewing conceptual change.

The power of this distinction is that it predicts significant differences in the research and its applications. (In the case of the seminar, the term predict is inappropriate - the seminar preceded this analysis, so for these people the distinction just discriminates. I use the term predict in a more general sense - people who hold a particular perspective are likely to do research in this way, on this type of question, etc). In order to demonstrate this predictive (or discriminatory) power, I will try to apply the two perspectives:

(i) Type of research question.

From a revolutionary perspective position, the important research questions would be of the following type:

- Can we identify specific frameworks?
- Are particular frameworks held by children applied consistently over different tasks and contexts?
- How widespread are particular frameworks in different populations of children?
- How can change in frameworks be brought about?

From an evolutionary viewpoint, the important research questions would be:

- What relationships exist between concepts?
- How can we measure (or observe) integration and differentiation?
- What approaches help the student to link new ideas to the most appropriate existing knowledge structure?

(ii) Context of Research.

The researcher with a revolutionary perspective would concentrate on pre-instructional scientific concepts, especially where the concept word is one which has common world meanings as well as scientific ones. There will also be a tendency for the context to be syllabus-neutral.

Concentration on pre-instructional beliefs follows from the realisation that the teacher needs to know the alternate frameworks that are present in her/his class if (s)he is to encourage change of framework. Concentration on areas where scientific words have common world meanings is important because in these cases there is greater potential for a wide range of particularly resilient alternate frameworks. Whether the research takes place within a particular syllabus or not will depend on other issues of interest. It does not have to be conducted within the context of a particular syllabus. (For example, although David Shipstone is interested in children's ideas about electrical currents which is part of the syllabus in particular years, he investigated students from forms 1 to 6.)

. The researcher with an evolutionary perspective would be likely to examine students' conceptual development within a specific teaching sequence for a particular syllabus. This is so because s(he) is interested in the way in which specific new ideas are integrated and differentiated from the learners' present conceptual knowledge (and how that is altered by the new ideas). The episodes of the teaching sequence will be important to her/him, for they are the 'new ideas' that the learner is to integrate and differentiate. This type of researcher will probably attend the classes of interest and record the events that occur. (As an example, Pines investigated the changes in the cognitive structures of young children before and after a set of audio-tutorial lessons.)

(iii) Presentation of data

. Researchers with a revolutionary perspective will usually report classifications of children into categories of alternative framework or conceptual type. (For examples of this see Erickson, Engel and Driver, Solomon.)

. Researchers with an evolutionary perspective will present data for individual learners in a way that emphasises relationships. They will use maps, network diagrams, tree diagrams, burr diagrams, etc. (For examples see Ross, West, Pines.) When they combine data from individuals to describe groups, they will use some combination based on relationship, integration, differentiation, etc. (See our Indices of Cognitive Structure (West et al), and Shavelson's relational matrices.)

(iv) Pedagogical implications

. The type of implication proposed by researchers from a revolutionary perspective will be:

- To encourage teachers to seek feedback about the presence or frequency of particular frameworks (see Nussbaum, Novick).

- To encourage and explore teaching strategies that capitalise on the existence of different frameworks. (For example see Nussbaum and Novick's use of discrepant events, Gilbert's encouragement of 'negotiating' meaning* and his use of interviews about instances between students, Solomon's encouragement of her students to articulate and argue about their concepts.)

. Pedagogical suggestions from "evolutionary" researchers will be:

- To encourage teachers to seek feedback about relationships, integrations and differentiations formed.

- To encourage students to produce their own concept maps as an aid to learning. (See Novak 1981 or Sutton's analyses of the gradual change in the meaning of words.)

- To use pre-instructional organisers to make explicit the link of new learning to specific elements of existing knowledge.

(v) The Role of prior knowledge in subsequent learning

. Those taking a revolutionary view would see children's present knowledge a potential barrier to subsequent learning.

. Those with an evolutionary one would see prior knowledge as the interpretive framework for subsuming subsequent learning.

Perspectives of the seminar participants (?)

In working out the above differences, examples may help to put flesh on the bones, and help us to share (or is it negotiate?) the meanings of "revolutionary" and "evolutionary". I have therefore tried to classify the participants into the two perspectives. I want to emphasise again that I do this because it helps us understand their work and not because I want to place some label on them. I want also to emphasise that I place no differential value judgement on those perspectives; all the participants are making important contributions to the general understanding of the development of children's ideas about science.

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* It is worth noting the connotations of the word 'negotiate' - it implies different positions (frameworks?) and change. Contrast it with Gowin's description of teaching as the 'sharing' of meaning.

Those who seem to be working from a revolutionary perspective are Driver, Engel, Erickson, Gilbert, Shipstone and Solomon. I am less certain about Ross. He generally appears to occupy an "evolutionary" position, but presents group summaries. Those who seem to be working from an evolutionary perspective include Crookes, Pines, Sutton and myself. Claxton, Head and Pope did not describe examples of their research directly. Pope presented an overview of Kelly's theory, and this distinction does not help in that regard. Claxton and Head acted as reactants at the seminar. I suggest that they are perhaps closer to a revolutionary perspective.

Specific examples

To help this analysis further I have taken two examples, one for each perspective. The people I chose are Erickson and myself. (It seemed fairer to me to dissect my own motivation rather than someone else's.)

. If we accept that Erickson is working from a revolutionary perspective position what would we predict he would do? He may:

- be concerned with identifying alternative frameworks, their nature and incidence;
- use concept words that have real world meanings and investigate them in situations separate from normal teaching;
- investigate these concepts prior to normal instruction in them;
- classify pupils into a small range of alternate frameworks and provide descriptions of those frameworks;
- view these frameworks as possible barriers to science learning;
- want to communicate this information to teachers.

When we examine his papers, we find considerable congruence with these predictions. His latest work concerns vectors, not the concept itself but the characteristics of vectors (often assumed) that children derive from their real world experience. He interviewed grade 10 students, prior to instruction. The interviews were analysed by classifying students into categories (of inferred rules) for a range of implicit vector characteristics. The aim of the study was to identify patterns of pre-instructional conceptual knowledge that may aid or inhibit the learning of vectors in science classrooms. He believes that knowledge of these preconceptions should be of value of science teachers and to curriculum designers.

If we classify my own work as based on an evolutionary perspective, my research may:

- be concerned with relationships amongst concepts and propositions,
- be part of a teaching sequence,
- be about knowledge that is in a syllabus, whilst it is being taught,
- use networks, trees, etc., as representations of the knowledge,
- make pedagogical applications that place stress on relationships, integration, differentiation.

My research with Jan Garrard and Peter Fensham was in fact about the understandings of chemistry students in several segments of teaching (e.g. amino acids, protein and peptides, radio-chemistry, single component phase diagrams). The knowledge investigated was student-generated propositions, skills, examples, images, all derived from the syllabus and teaching. The descriptions were network diagrams. We collapsed these networks into indices of cognitive structure - and these indices described features such as propositional integration, skills differentiation, and articulated propositional relationships. When discussing the application of the research, I described a study that asked whether teachers could use the techniques to obtain feedback from their students about the integration and differentiation of their acquired knowledge.

We should examine too the similarities between Erickson's research and my own. Both of us have used individual interviews to collect our data; both have assumed that conceptual knowledge has elements of idiosyncracy (or private understandings) that are worth investigating; both have assumed that learning is more than repeating what has been taught - that conceptual knowledge is re-interpreted knowledge; both have assumed that prior knowledge is an important determinant of subsequent learning.

Concluding comments

I have tried to develop a framework that helps the reader to understand this new area of research, its directions and its purposes. There may of course be better ways of dissecting the 'beast' (or is it an insect?), but I have found this particular one very powerful, and I hope that readers will find it similarly so.

In case I have given a wrong impression, there are other differences between the participants. For example, some are more student-centred, some more teacher-centred. I did explore a range of these differences but found them less fruitful for this purpose than the one I have used here.

Some further references

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THE ORIGINS OF PUPILS' IDEAS

Clive Sutton

Whence come these "minitheories", "alternative conceptions" or "frameworks of interpretation" that researchers claim to have found? If we could clarify our assumptions about that, then we would have a powerful guide to further enquiries, and to the practical business of teaching and learning. Just HOW we think people's ideas arise bears especially strongly on how they might change. A fully articulated theory about it would surely indicate tentative answers to the questions posed elsewhere in this report about whether such ideas are stable or unstable, when they might be resistant to change, and whether change is better thought of in evolutionary or revolutionary terms.

Therefore I want to survey some of the explicit statements about origins that the participants brought with them to the seminar, and to try to relate these in a more unified theory of how practical experience and language use may bring about changes in meanings. I draw particularly on my own belief that figurative uses of language are a key part of "figuring things out", and on the Brunerian notion of language as an amplifier of thought.

Ageha Claxton was particularly explicit about where children's ideas might come from - "gut science" from the child's immediate experience, "lay science" from the speech and other media of communication around him (see page). Driver and Erickson also speculated on possible sources (see page), and of course the users of Kelly's Personal Construct Theory also give a partial account of children's ideas, seeing them as HYPOTHESES, or ANTICIPATIONS of events.
(That pushes my question further back: where do hypotheses come from?)

Drawing these contributions together, we can summarise as follows. A child's ideas might arise...

1. FROM IMMEDIATE physical EXPERIENCE

2. FROM AVAILABLE LANGUAGE, especially AVAILABLE METAPHOR

3. FROM THE BELIEFS & OPINIONS allowed & encouraged by PEERS

4. FROM "INSTRUCTION" formal & informal.

Words not needed?

Is the first of these sufficient in itself? The enactive experience of the learner provides a source of mental reference, guiding future actions. Objects one has slid on real surfaces give an intuitive picture of how motion changes, the kinaesthetic memory of being buoyed up in water, gives the experiential basis for trying to float other objects. In a Brunerian sense it is this enactive representation of knowledge which seems most basic to human understanding. If we based the research entirely on what chilren DO, rather than on their verbal explanations, perhaps we need go no further. Early experience of sliding things guides the child's actions in a predictive way. She "knows" how hard to push the schoolbag to slide it along the floor to a friend. The first time she uses these anticipations on an ice rink there would be some surprises, but presumably a successful revision of the minitheory would occur quite soon - and all without the intervention of words at all!

A minitheory in this sense appears to be a remnant from experience, which doesn't necessarily have any explicit verbal statement.

The mind's eye and the mind's mouthpiece.

...It could however become the basis for generating verbal statements. "It's slippy ...soapy ...skiddy ...greasy ". There are many possible choices of words, and each one could become the starting point for an elaboration of thought, even if the child has not reflected much about the topic before.

That is how human thought has always been elaborated. As Bruner points out, the explanatory and predicitve systems that we generate rapidly move into a form that is more independent of concrete experience, involving images and symbols that can be shunted around with great flexibility.
(I leave it to others to find out if this has anything at all to do with the right and left halves of the brain.)

Since the researchers encourage pupils to articulate their beliefs, they place them in a position of having to search for appropriate words. In this respect learners are no different from any other human beings, and it seems to me that their conceptions arise by the same mechanisms of human intelligence that have brought about new or changed ideas anywhere. Hence it is necessary to look more generally at the evolution of ideas, and the related evolution of language.

For children or for creative scientists, the second of our sources of ideas turns upon the interplay of imagery and speech. The mind's eye guides their choice of words as they describe what they believe is going on. "It's as if there were a current flowing in the wire." .... "It's as if electrons were in orbit round the centre of the atom" ... "It's as if it made a quantum leap".

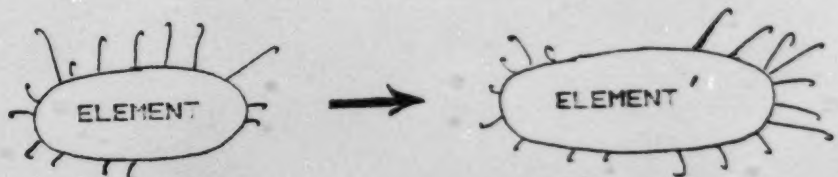
Major scientific theories can be traced to this search for words, guided by imagery. What else did their originators have to draw upon but the available language of the time? They used it as an interpretive device, reapplying old words in new situations. So the first theorists about electrical phenomena came to speak of bodies being "charged" up to the limit of their "capacity", and modern ecologists have come to describe organisms as occupying their "niches" in the biosphere.

If pupils today are using their intelligence in this way, they too will draw upon images available, and words they have encountered. I suspect that if their explanations seem deficient to the mature observer, it is because of a poverty of imagery, or a poverty of available words, or both, rather than imprisonment in a particular straitjacket of thought. Where a particular explanation is very common in a school population, we should enquire into the imagery and/ or vocabulary that is pervasive in that culture.

Meaning drift.

Whenever words are reapplied and put to a new use they suffer some change in meaning. Some of their connotations remain unchanged, some are neglected and may be forgotten altogether, and some are emphasised much more, so the "centre of meaning" shifts. A good example would be the word ELEMENT before and after the time of Boyle. Before his time it would certainly have triggered associations for many people of something fundamental, important, basic. Some would have been minded of Euclid (The Elements of Geometry), and many of earth, air, fire and water. A few would perhaps think also of mercury, and sulphur. Even today, the abstract aspects, and the earth air fire and water, are still part of the total possible meaning of this word, but ever since Boyle, they have been much less central, as attention has shifted to that part of the original meaning which suggested a tangible stuff - something you could hold in your hand, and try to decompose into other material stuffs. Mercury, yes, and iron too, but not any more the intangible "principles", "essences" of the earlier period.

These changes can be suggested in outline, using the burr notation for a concept and its word-label.



Changes in conceptual structures always involve changes in word meanings, and I suspect that that is what happens for pupils too. "Current" today may be used only in statements about rivers, but tomorrow it may be used to describe the movement of cars on a motorway, and when talking about something in a copper wire. The development of meaning seldom consists of total changes in how words are used, rather it consists of gradual enrichments, and acquisitions of subtlety, as any teacher knows who has helped pupils to refine their initial understandings of "oxidation" or "respiration" over several years.

Peers, instructors, and other features of the social milieu

What then of items 3 and 4 in our list of possible sources? Perhaps they are just suppliers of images and of words. TV and teacher, pop group and playground; all may offer words or images upon which the active mind could draw when in the sense-making business.

There is however, another aspect to this, which mirrors in the school something that applies more generally to the evolution of ideas in society. (This section is based partly on conversations I have had with Leon Pines about Stephen Toulmin's notion of evolving populations of concepts). An evolution as we understand it biologically requires a SOURCE OF CONTINUOUS VARIATION, and a MEANS OF SELECTION that causes differential mortality. When scientific ideas evolve, we can account for the variation in this way: no two people have exactly the same meaning for any word, and novel usages spring up continually in the manner described above. Some of them tease the originator's mind into action, and the exploration of their implications results in a fully worked out theory. Selection then occurs, through the public scrutiny given to the new theory by the community of scientists. Only a few of the new insights formed by individuals survive to become established public knowledge.

Similarly, in school, the peer group, and any other groups that are emotionally important to the learner, may act as a sanctioning system that will either legitimise the individual's new insights, or refrain from doing so. It therefore becomes important to know how these groups are acting as a reward system, and source of emotional satisfaction, to the learners.

Conclusions

1. Some "theories" can evidently exist without any verbalisation at all, but language extends their power immensely. Any learner's choice of words is based on some underlying imagery, and this might form a useful focus for further research.

2. The role of language in the formation of new ideas turns on figurative uses of old words, which give their user a new insight, and new implications to explore mentally. Eventually this causes changes in their "centre of meaning". For a learner, learning consists of successive shifts of meaning of this kind.

3. The social milieu of the learner can affect the process both by providing a stock of images and words, and by sanctioning some but not all of the mental constructs that he or she makes out of them, and the statements he or she makes as a consequence.

Descriptions of "alternative frameworks" may be less useful in the long run, than a system for observing the gradual shifts in pupils' use of language, as the range of meaning that they ascribe to key terms developes, and the range of uses to which they can put these terms increases. One might begin with free definitions of key terms, and free associations, as used by Schaefer, but add the following:

(i) ask the learner to construct several sentences showing ways in which they can use a key word. .."How else have you heard that word used?"

(ii) ask them "what they see in their mind's eye".

(iii) when a learner uses a particular form of words to explain something, ask "Why did you describe it like that?" and "What made you think that?"

(iv) draw up a catalogue of the experience likely to be available to this learner, including:
- likely tangible experience
- images available from the media, home, etc
- language accessible as support to those images

(v) inspect the established language of the topic, and the way people speak about it at home. Since the language is itself a product of evolution, and contains the fossil remnants of ideas that were important long ago, these may be part of the resources that the learners are using to construct their courrent understanding.

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WHAT IS THE VALUE OF THESE STUDIES?

by Leo West

This is a new field for research in science education. Most of the researchers around the world know each other personally. There are, as yet, relatively few publications, but many circulating research reports. It is one which is growing fast and gaining acceptance. This seminar was an opportune time, not just to meet and talk but also to reflect on the endeavour itself. What value does it have, For whom? What are the dangers for the research movement itself? In this section I have tried to summarise the various opinions expressed during the seminar about these issues.
(a) What value does the research have external to itself, and
(b) What is the value, or indeed what are the dangers within the research movement?

External value

Even today much of science teaching in schools and colleges follows a transmission model, implying an inputs → black box or inputs → black box → output model of learning. An instance of this can be seen in the discovery learning movement, in which the notion of discovery has become distorted to "guided" discovery. (It is most informative to read Chapters 2 and 3 of Joan Solomon's book Teaching Children in the Laboratory.) I am not suggesting that this research provides a rationale for (or indeed against) discovery learning. What it does provide is an essential ingredient for both discovery and expository teaching that has potential to make the resultant learning meaningful, because it focuses on the nature of the students' learning.

It seemed to me that one of the unusual assumptions of participants at the seminar (and an assumption that is being supported by research) was that children need to construct their own learning. The inactive taking in of pieces of isolated knowledge leads to rote learning. For pupils to make sense of the knowledge they encounter (either as formal instruction or informal learning) they must reinterpret or reconstruct that knowledge in their own way.

A second shared assumption (also being confirmed by research results) is that the learner's present knowledge is important in their response to new ideas. Sometimes this existing knowledge will form a barrier; at other times it will act as an interpretative framework.

This leads to a "functional" implication for science teaching. It should be part of science teaching that pupils be given the opportunity to re-interpret new information. The research provides some examples, but not prescriptions, about how this might occur. These include:

. Opportunities for pupils to articulate, without value judgements, their current relevant knowledge (Solomon, Nussbaum and Novick),

. Opportunities to negotiate the understandings to be placed on a particular segment of teaching (Pope and Gilbert).

. Indications of the historical changes in the meanings of key scientific words (Sutton).

. Student exercises in constructing representations of their own cognitive structures (West).

. The keeping of an ideas diary to help the student appreciate the development of her/his ideas (Crookes)

... and so on.

There is another side to this coin: that which is sometimes called the affective. Why should pupils attempt such re-interpretations? Why should they take on new views? Why should they bother to resolve dissonance between their own view of the world and that presented by their science teacher? There was awareness of these issues (and we were continuously prodded by John Head in this direction), but few answers yet. The optimists had various suggestions (e.g. meta cognitions); the pessimists pointed to the reward systems in schools and colleges as the major stumbling blocks.

Further, why should teachers change their behaviours? What could motivate them to adopt quite different and patently threatening strategies? One answer to this derives from research which identifies the proportions of polulations who have specific alternate frameworks (Engel and Driver, Erickson, Gilbert). These results have potential to shock. They indicate a degree of conceptual problem which most teachers and curriculum designers might not have expected. Knowledge of these results makes their consequences hard to ignore.

Nonetheless we (the researchers) should approach these questions with a great deal of humility. It is easy to cast pebbles, but for those in the pond who are struggling to stay afloat, the resultant ripples may be of little significance.

Internal value

In any new field there are problems of growth. Some of our discussions were directed inwards at the movement itself. Where is it going? What dangers should it avoid?

Pines identified one danger: the development of elegant, if simplistic, models that have potential to generate many research projects but little else. A similar statement of the same danger was that of researchers "butterflying" around the curriculum examining this concept here, that concept there, and so on.

A more subtle danger is the hardly perceptible shift from investigating children's ideas about science (and how they develop) to the testing of micro-theories of teaching. This was the trap that snared much of the research on Ausubel's theory of learning, as research shifted from investigating a powerful but difficult-to-test theory of learning to testing insignificant, but related, theories of teaching, i.e., should advance organisers be placed before or after the instruction?

This new area of research probably has as much potential as any in the past to make a significant impact in science teaching and learning. Whether it realises that potential or not depends, in large part, on avoiding the dangers of the Bandwagon and of the Esoteric Research Group unconnected with classroom research.